Assessing Browse Trend At The Landscape Level Part 1: Preliminary Steps And Field Survey

By Richard B. Keigley, Michael R. Frisina, and Craig W. Fager

Woody plants are an important component of rangeland habitat, providing food and shelter for animals that range in size from moose to warblers to insects. Because of this importance, land managers are paying increased attention to browse trends. In this two-part article, we describe how browse trend is assessed at the Mt. Haggin Wildlife Management Area in southwestern Montana.

Located south of Anaconda, Montana (Fig. 1), winters are extremely cold and windy at the Mount Haggin Wildlife Management Area. The annual precipitation is about 20 inches, much of which occurs as snow.

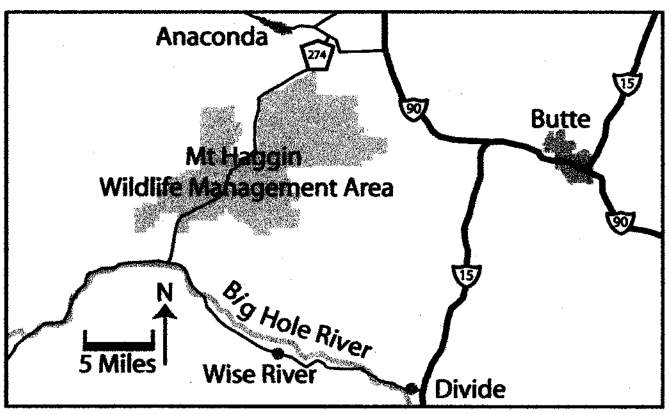

Fig. 1. *Map of study area.*

There are resident and transient ungulate populations. Moose is the only ungulate species present in all months. Elk, mule deer, and pronghorn antelope are present much of the year, but cannot contend with the deep snow cover that exists during mid-winter. Whitetail deer and cattle are present during the warm season. Cattle are managed under a three-pasture rest-rotation grazing system.

During the fall, a significant transient moose population is present. As snow cover deepens in the Pintler Mountains to the west, moose migrate from those mountains and stage in the area before migrating to lower elevation winter range in the Big Hole Valley. Over the past three decades, the moose population has increased. Censuses by Montana Fish, Wildlife & Parks in the 1970s reported an average of 9 animals; in 1980s, an average of 19 animals was reported; in the 1990s, an average of 39 was reported.

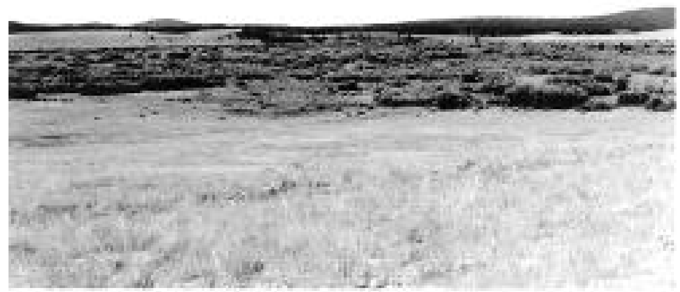

Fig. 2. *Willow community provides critical habitat for wildlife.*

Willows present in the study area include Geyer, Drummond, Booth, planeleaf, Scouler, and Wolfs willow (Fig. 2). The riparian species are found in two general kinds of valley bottoms. At the lower end of drainages, the valleys tend to be wide and flat-bottomed, and locally bordered by glacial moraines. Within some of the flat-valley-bottom areas, willow communities are confined to the corridor immediately adjacent to relic or current stream courses. At other locations, ponding caused by beaver dams, has allowed willow communities to spread across a broad area. At the upper end of the drainage, willows are confined within relatively narrow, v-shaped valleys. In the upper drainages, conifers often are present within the willow community.

Willows are currently heavily browsed (Fig. 3), but there is evidence that browsing pressure was lower in the past. Heavily-browsed 14-inch-tall plants grow in close proximity to 16-foot-tall plants, the tallest stems of which are unbrowsed (Fig. 4). The 16-foot-tall stems are older than the 14-inch-tall stems, and apparently grew through the browse zone when browsing pressure was lower than its current level. An increase in browsing pressure would be consistent with the increase in the moose population that occurred over the past 3 decades.

Our trend assessment involved five steps. Steps 1 through 3 were preliminary to the actual assessment of trend. Actual trend assessment occurred during steps 4 and 5.

Fig. 3. ***Heavy browsing produces clusters of twigs at the ends of stems. A substantial portion of this shrub is dead.***

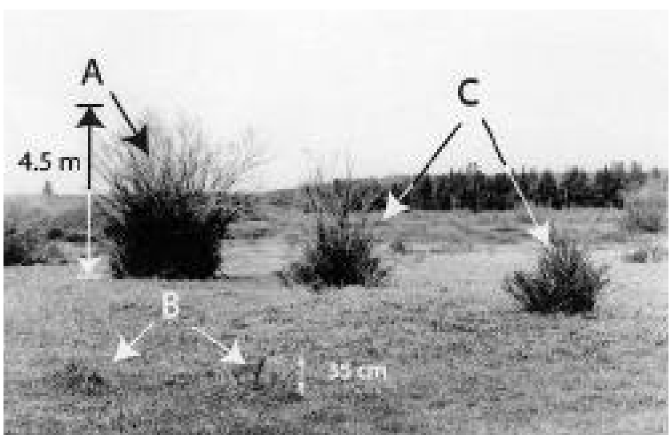

Fig. 4. ***A qualitative history of browsing can be interpreted by observing the relationship between plant height and plant age. In this case, an increase in browsing pressure has prevented young willows from attaining full stature.***

Step 1: Identify relevant management objectives

The management of the browse resource was linked to area-wide management objectives. Two such objectives were deemed especially important. First, the area was purchased to provide winter range for big game. To serve as winter range, browse plants must be available for ungulate use under snow cover that ranges from negligible early in the winter season, to snow that lies more than 3- to 4-feet deep in mid-winter.

Common and scientific names of species.

Wild Ungulates	
moose	*Alces alces*
American pronghorn antelope	*Antilocapra americana*
Rocky Mountain elk	*Cervus elaphus*
Rocky Mountain mule deer	*Odocoileus hemionus*
Whitetail deer	*O. virginianus*
Plants	
dogwood	*Cornus stolinifera*
spruce	*Picea engelmannii*
Booth willow	*Salix boothi*
Drummond willow	*S. drummondi*
Geyer willow	*S. geyeriana*
Planeleaf willow	*S. planifolia*
Scouler willow	*S. scouleriana*
Wolfs	*S. wolfi*

In addition, Montana Fish, Wildlife and Parks is committed to providing habitat for a variety of game and nongame wildlife. For example, Mt. Haggin Wildlife Management Area provides nesting habitat for sandhill cranes and neotropical migrants. Accomplishing these management objectives requires the presence of appropriately-sized woody plants.

At Mt. Haggin, willows range in height from very small, young plants, to older plants more than 16-feet tall. The preservation of this diversity in plant heights is essential to meeting the management objectives. Formally stated, the management objective is: *Plants of diverse heights will be present, ranging to the full height potential as determined by local environmental conditions.*

Full-statured plant stems (say those that grew to 16-feet tall) have a finite lifespan. If full-statured stems are to persist in a community, young stems must grow to full stature to replace those that die of old age. Heavy browsing can prevent young stems from growing through the browse zone. Continued long enough, heavy browsing can lead to the elimination of entire browse plant communities.

To maintain a plant community of varied heights, browsing must be light enough to allow young stems to grow through the browse zone and attain full stature. We used three methods to examine the fate of stems as they attempted to grow through the browse zone (architecture, stem height, and growth rate). Because full-statured stems are relatively long-lived, it is not necessary that *all* young stems grow to full stature—just *some*. Thus we look for evidence that browsing has prevented *all* young stems from growing tall.

Step 2: Indicator species

We focused on a single indicator species. That species should have two characteristics. First, it should be among those preferred by ungulates. A highly-preferred species (such as dogwood) is a more sensitive indicator of browse impacts than less-preferred species (such as spruce). Second, the indicator plants should be widely distributed across the managed area. From this distribution, managers can determine how browsing level varies across the landscape. We selected Geyer willow as the indicator species.

We assume that the fate of other browse species is indicated by the trend of Geyer willow. If Geyer willow is in decline, the decline of more-highly preferred species would already have occurred. As the amount of available Geyer willow diminishes, less-highly preferred browse species will begin to decline.

Step 3: Delineating the distribution of the indicator species

We prepared a map on which we estimated the total distribution of Geyer willow in the study area (Fig. 5). We

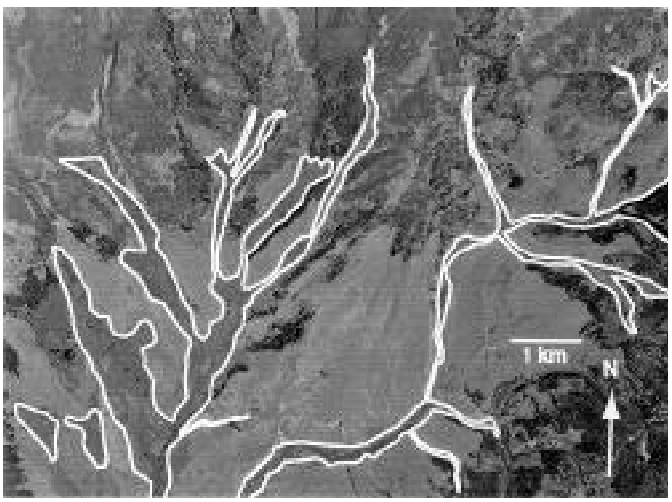

Fig. 5. ***Map showing distribution of Geyer willow. This map served as the basis for selecting areas for surveying and monitoring.***

used the map to prioritize the subsequent steps of field surveying and monitoring. The map was based on a combination of site visits and by examining willow canopy cover on 1:12,000 aerial photographs. From site visits, we determined that Geyer willow extended across the full elevation range included in the study area. This distribution implied that, if any riparian willows were present in an area, Geyer willow plants would likely be included.

Because the map was to be used primarily for prioritizing future work, it was not necessary that the willow community boundaries be precisely drawn. In our case, high quality aerial photographs made the job relatively simple. This step could also be accomplished using images downloaded from the Internet or by delineating the approximate community boundaries on a topographic map.

Assessing Trend—Some General Comments

Trend was assessed using two approaches: field surveys and monitoring. During surveys, emphasis was placed on rapidly covering a broad geographic area. During monitoring, more-detailed data were collected from fixed locations; those same locations will be resampled periodically.

In the course of assessing trend, three different questions were addressed:

1. In recent years, have plants been able to grow through the browse zone? (This question is addressed in field surveys by examination of plant architectures.)
2. Over the long term, are plants growing taller? (This question is addressed during monitoring by comparing the height of live stems to the height of stems killed by browsing.)
3. Do plant stems grow fast enough to grow out of ungulate reach before they die? (This question was addressed during monitoring by determining stem lifespan and by measurement of growth rate.)

The data collected during surveys and monitoring complement one another; managers can emphasize one type of data over another to suit their needs. If it is most important to determine how browsing level might vary across the landscape, the manager can emphasize the survey component. Alternatively, managers wishing to track short-term changes in browsing impacts can do so with the type of data collected during monitoring.

Step 4: Trend assessment by field surveys

Field surveys document two aspects: a) browsing level, and b) plant height. Browsing level is an indicator of trend. Plant height indicates the availability of browse during winter. And if the community is in decline, plant height provides a rough indication of persistence; tall willow plants, with some stems out of ungulate reach, appear to live longer than shorter willows in which all terminal leaders are heavily browsed.

Below, we describe two field surveys, one conducted on a segment of Sullivan Creek, the other on a segment of Deep Creek. Both areas contain willows that range in height from very short, young plants (e.g., 8 inches) to older plants that are more than 16-feet tall.

Browsing level. Two levels of browsing are distinguished: a) intense, and b) light-to-moderate. In Keigley and Frisina (1998) we present specific rules for determining if a stem is intensely browsed. Intense browsing occurs when a complete annual segment is killed; current-year-growth develops from a segment older than the previous-year's-growth. Under light-to-moderate browsing, current-year-growth consistently develops from the previous-year's-growth. These rules apply at the stem level.

At the whole-plant level, browsing level affects plant architecture (growth form). We have identified four architec-

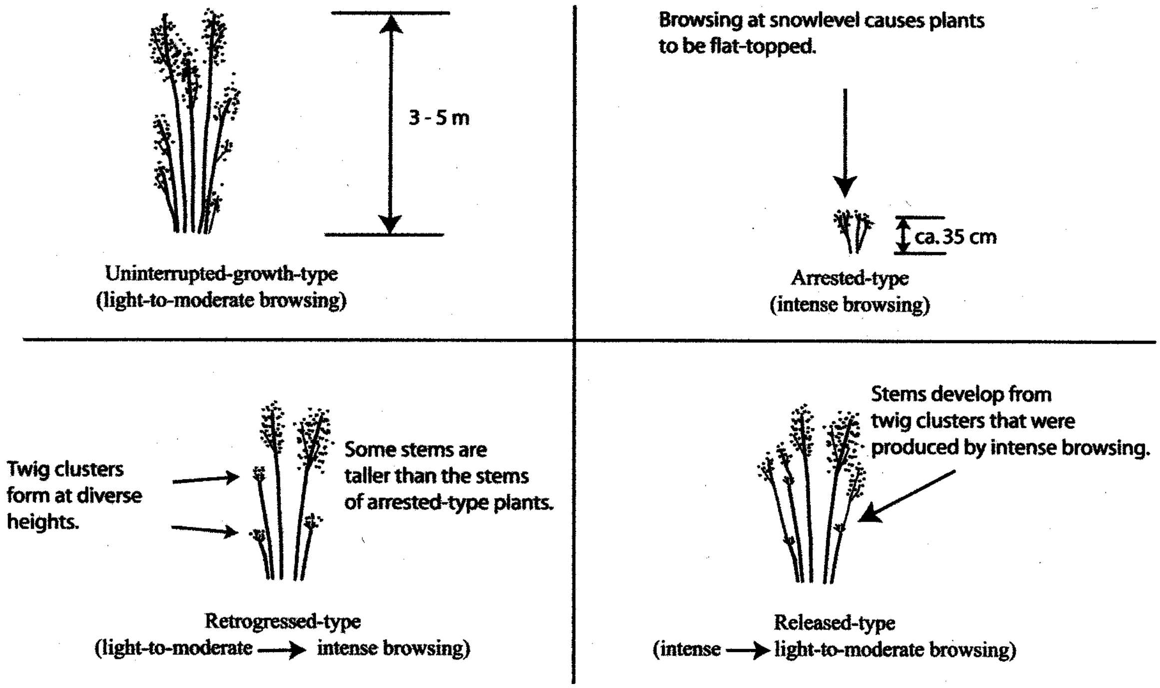

Fig. 6. ***Browsing-related architectures.***

ture-types that correspond to four browsing regimes (Fig. 6). The architectures are produced during the period of time that the terminal leader grows within the browse zone. They are:

a) Uninterrupted-growth-type architecture (produced under light-to-moderate browsing conditions),
b) Arrested-type architecture (produced by intense browsing),
c) Retrogressed-type archtecture (produced by a change from light-to-moderate browsing to intense browsing), and
d) Released-type architecture (produced by a change from intense browsing to light-to-moderate browsing).

Because these architectures are mainly produced when the plant is young, one can interpret the browsing history of a site by examining plants of different age.

To assess trend, we examined the architecture of plants with terminal leaders in the browse zone. At Mt. Haggin, the browse zone extends from a lower limit of about 8 inches (20 cm) above ground level to an upper limit of about 8 feet (2.5 m). Plants are apparently browsed at 8 inches early in the winter season as snow begins to accumulate. The upper limit of the browse zone is controlled by ungulate reach. Stems greater than about 5 feet (1.5 m) may be out of direct reach of deer and livestock; elk and moose can reach upwards of 8 feet (2.5 m). Browsing at heights greater than those upper limits can occur when ungulates stand on crusted snow, stand on hind legs, or bend stems to the ground.

We characterized the level of browsing by examining the architecture of plants in which the base of the terminal leader was between 30 and 60 inches (75–150 cm) tall. Plants in this height range likely were exposed to browsing during recent winters.

We distinguished between two situations: a) *all* plants exposed to browsing have arrested- or retrogressed-type architecture (mapping unit: “100% intensely browsed”), and b) *some* plants exposed to browsing have uninterrupted-growth- or released-type architecture (mapping unit: “<100% intensely browsed”). In the case where all plants have arrested- or retrogressed-type architecture, it is probable that no young plants will attain their potential height. In the second case, some plants apparently will attain full stature, and the desired condition will be maintained or attained.

As we traversed the field survey area, we delineated the willow area on an aerial photograph. We partitioned that area into the two mapping units described above. As we moved through an area, we sought out plants that might have uninterrupted-growth- or released-type architecture.

Measurment Units

Our methods involve relationships between small lengths (stem growth rates that are sometimes less than one inch per year) and large lengths (plant heights greater than 8 feet). Because calculations involving inches and feet are cumbersome, field measurements were made in metric units.

Throughout the text, length measurements are described in English units, with values often rounded to the nearest inch or foot. The measured metric units are presented in parentheses.

When such plants were found, we tried to determine why they had escaped browsing. If a plant was deemed to have escaped browsing because of local protection, we discounted the architecture of that plant as an indicator of area-wide browsing pressure. Local protection of a young plant might occur when a taller neighbor inhibits ungulate access, either directly or by creating a deep snowdrift. When these circumstances were confined to a few square meters, we assumed that the protective effect was temporary.

Plant height. Plant height was documented by narrative description in the Sullivan Creek survey and by mapping in the Deep Creek survey. In the Sullivan Creek survey, we described the general circumstances under which willows greater than 10-feet (3-m) tall were found.

In the Deep Creek survey, we distinguished between three plant-height categories: a) Short (the plant is < 20-inches (50-cm) tall, symbolized by "S"), b) Intermediate (between 20-inches (50-cm) and 9.8-feet (3-m) tall, symbolized by "I"), and Tall (> 9.8-feet (3-m tall), symbolized by "T"). Plant-community height characteristics were described using combinations of the three categories: S, I, T, SI, ST, IT, and SIT. For example, a community composed of willows less than 20-inches (50-cm) tall and willows greater than 9.8-feet (3-m) tall would be designated ST. A site that has experienced protracted intense browsing may be composed entirely of plants in the S category. During the winter, plants in the S category often are buried by snow and unavailable to ungulates. Plants in the I and T categories are a source of browse under diverse snow cover conditions.

Category T was distinguished because stems greater than 3-m tall often escape browsing. The presence of tall terminal leaders might allow a shrub to persist longer than shrubs that solely consist of shorter terminal leaders that are all heavily browsed. As in the mapping of browsing level, the total willow area was delineated on an aerial photograph and partitioned—as we traveled across the area—into the 7 mapping units listed above.

Deep Creek field survey. The surveyed segment was about 0.6 miles (1 km) long; willow covered 270 acres (110 ha) (Fig. 7). The entire area was classified as 100% intensely browsed. As above, the few uninterrupted-growth type plants were growing in vicinity of taller, heavily browsed, neighbors. We assumed the mechanical protection was temporary.

Stands that included willows greater than 9.8-feet (3-m) tall constituted 33% of the total willow area of 89 acres (36 ha) (Fig. 8). The remainder of the area (i.e., 67%) consisted of willows that ranged in height from ca. 8 inches to 8 feet (20–250 cm) tall. While we currently have no basis for quantitatively predicting the rate of decline, we do know that 67% of the willow area is susceptible to a relatively rapid rate of decline.

Sullivan Creek field survey. The surveyed segment of Sullivan Creek was about 2.2 miles (3.5 km) long; willow covered 570 acres (230 ha) (Fig. 9). The entire area was classified as 100% intensely browsed. Uninterrupted-growth-type plants were uncommon. In each case, we could identify how the plant was mechanically protected from browsing. If current browsing pressure continues, the protection will be temporary. As the plants adjacent to the uninterrupted-growth-type plants die, moose will focus on the remaining live plants.

Willows greater than 9.8 feet (3 m) tall grow in linear zones along current and relict watercourses. Linear zones of tall willows are also associated with beaver dams. Many of the ponds have drained, allowing willows to become established there; these willows range in height from about 8 inches to 7 feet (20–200 cm) tall. Willows could have become established on the beaver dams when the ponds were still filled with water, so in part, willows growing on the dams may be taller because they are older than willows growing on the former pond areas. In part, the difference in

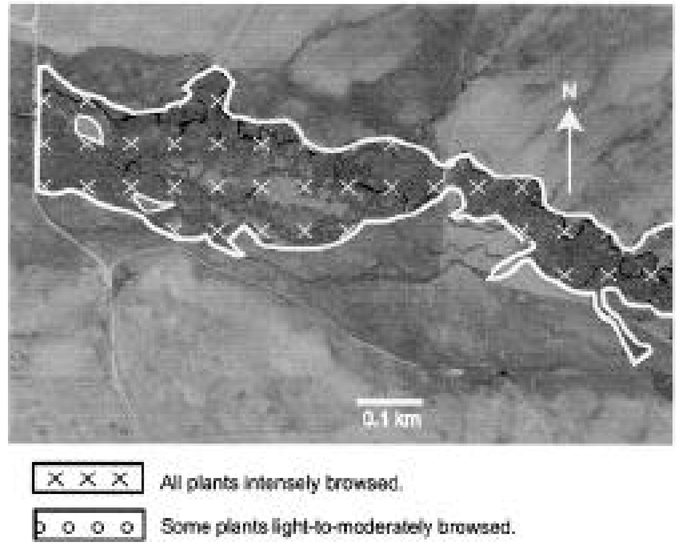

Fig. 7. ***Browsing intensity on Deep Creek segment of field survey. The entire area was 100% intensely browsed.***

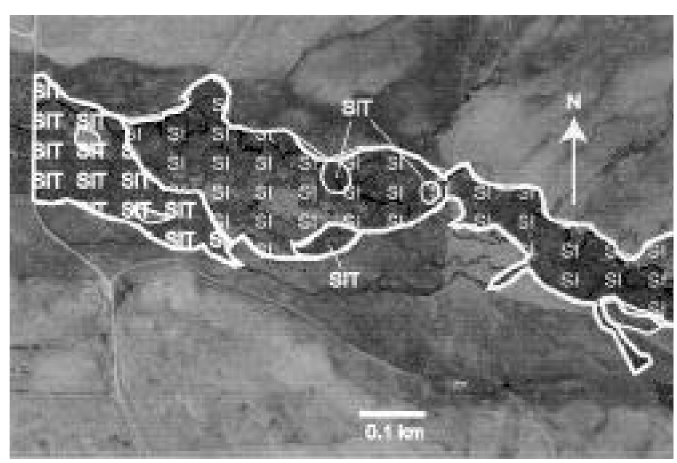

Fig. 8. ***Willow height at Deep Creek segment.***

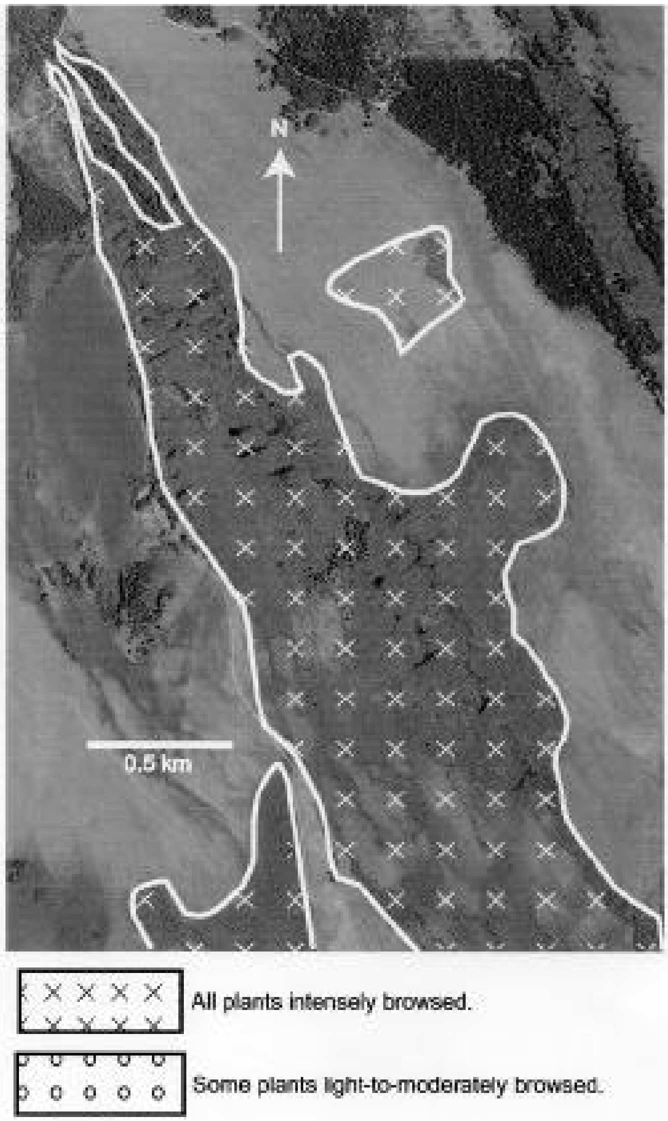

Fig. 9. ***Browsing intensity on Sullivan Creek segment of field survey. The entire area was 100% intensely browsed.***

height might be due to heavier browsing of willows growing in the pond areas. A dendrochronologic analysis of stems indicates that browsing pressure increased in the mid-1980s. Willows established since the 1980s would have experienced intense browsing while the tallest terminal leaders were within the browse zone. There is extensive mortality of shorter willows.

Summary of Part 1

We described above how plant architectures can be used to assess browse trend across large geographic areas. However, the statistical analysis of the architecture data is limited. In Part 2 of this paper we describe how browse trend was further assessed using quantitative data that were periodically collected at fixed sites. We refer to that phase of trend assessment as "monitoring."

About the authors: Richard B. Keigley, Ecologist, U. S. Geological Survey, Biological Resources Division, 632 Coulee Drive, Bozeman, MT 59718. Michael R. Frisina, Range Coordinator, Montana Fish, Wildlife, & Parks, Butte, MT, 59701-2112. Craig W. Fager, Wildlife Biologist, Montana Fish, Wildlife & Parks, 1820 Meadowlark Lane, Butte, MT, 59701

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Assessing Browse Trend at the Landscape Level Part 2: Monitoring

By Richard B. Keigley, Michael R. Frisina, and Craig W. Fager

In Part 1 (see page 28), we assessed browse trend across a wide geographic area of Mt. Haggin Wildlife Management Area by conducting surveys of browsing-related architectures. Those data were qualitative. Below we describe the periodic collection of quantitative data from permanently marked locations; we refer to this phase of the trend assessment program as "monitoring." Trend was monitored by three methods:

1. Repeat photography.
2. Comparison of the height of live stems with the height of stems killed by browsing (LD Index).
3. Net annual stem growth rate ($NAGR_{L3}$).

The photography provides an assessment of trend from the comparison of photographs taken at intervals of a few years. The LD Index and $NAGR_{L3}$ measurements provide an immediate assessment of trend.

Establishment of permanent stations. Three considerations entered into the location of monitoring stations. Based on observation of moose habits, the stations were located in areas heavily used by moose. The stations were dispersed across the area in which Geyer willow occurs. The sites are accessible with relatively little effort.

Each station's location was documented in 6 ways: a) small-scale map, b) narrative description, c) large-scale sketch map, d) GPS coordinates, e) photographs of surrounding area, and f) a steel fence post. The small-scale map and narrative description should locate the station to within about a hundred meters. The large-scale sketch map, GPS coordinates, and area photographs should lead a person directly to the steel post.

Four monitoring stations were established in 2000 (Fig. 1). Stations MS1 and MS2 are located in areas where field surveys were conducted (Sullivan Creek and Deep Creek). Station MS2 is located in a 30 ha fenced area from which cattle have been excluded since the mid-1980s; browsing effects at this station are unequivocally due to wildlife. Stations MS3 and MS4 are respectively located in the French and American Creek drainages.

Transect for repeat photography. Two kinds of photographs were taken: a) a panoramic series, and b) a photograph down a permanent transect line (Fig. 2). When taking the transect photo, the camera was positioned above the steel stake. The transect bearing was recorded on the sketch map. A metric tape was extended down the transect line. A

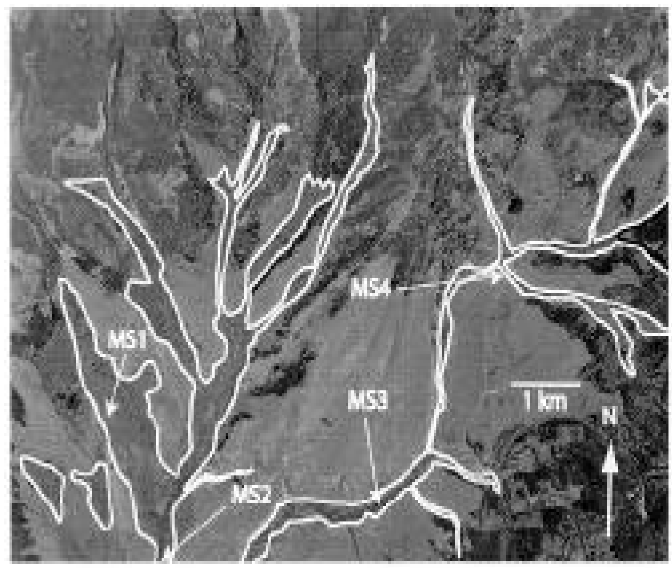

Fig. 1. ***Location of monitoring stations.***

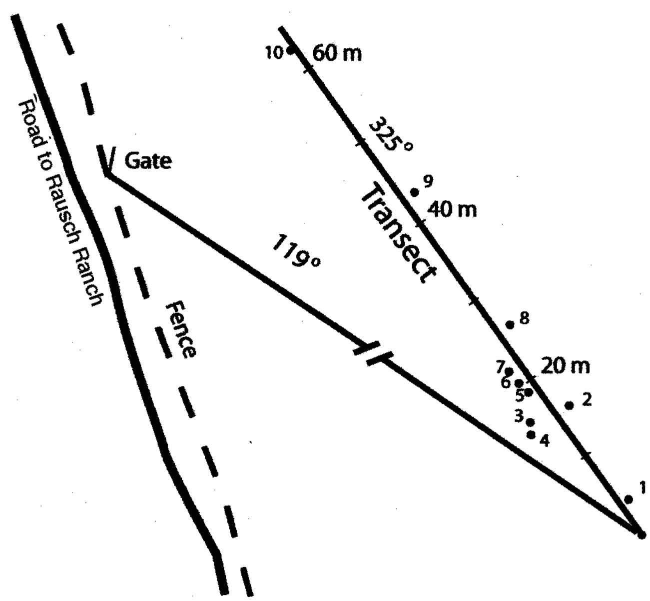

Fig. 2. ***Sketch map of transect at monitoring station 1.***

Fig. 3. ***Photograph down transect at monitoring station 1.***

metric stadia rod was included for scale; the location of the stadia rod was recorded on the sketch map.

Along the transect line, the location of 10 Geyer willow plants was documented by recording their distance along the transect line and their offset (N/S or E/W) from that line. Two heights were recorded for each plant: a) the height to the base of the tallest current-year-growth (H_{pyg}), and b) the height to the tip of the tallest stem killed by browsing (H_D).

A typical transect photograph is shown in Fig. 3. While photographs provide tangible evidence of plant condition, their interpretation is subjective. By documenting the location and measurement of 10 plants, we provide future viewers a limited quantitative perspective. The effect of browsing often is difficult to see in photographs that are taken late in the growing season when current-year-growth extends well beyond the twig clusters.

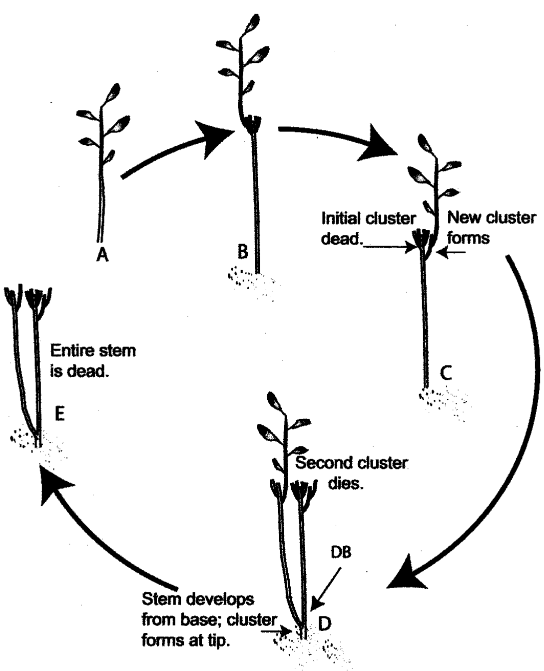

Fig. 4. ***Sequence of growth and death of a heavily-browsed stem.***

Trend assessment based on LD Index. This index expresses the difference between the height of live stems and the height of stems killed by browsing. The index was based on the following observations. Willow shrubs with dead stems are common throughout Mt. Haggin Wildlife Management Area. Such shrubs are typically composed of stems of different age as represented by the types shown in sequence A-E (Fig. 4). From establishment to death, a typical stem progresses through the following history. Stems are light-to-moderately browsed until they grow above snowcover or above other forms of mechanical protection (A).

Once the stem is available to ungulates, browsing causes clusters of twigs to form at the tip (B in Fig 4). After a period of time, the cluster-bearing portion of the stem dies, and one or more lateral branches develop from a lower position on the stem; these branches assume the role of terminal leader. The lateral branches might develop at the base of the original cluster (C), or may develop at the base of the original stem (D). Clusters of twigs form on the new terminal leader, and after a period, the new terminal leaders die. Finally, the entire above-ground portion of the stem dies (E).

The LD Index monitoring method is based on the difference in the height of stems killed by browsing versus the height of live stems. Where there are both live and dead stems present, there are three possible relationships:

a) Live and dead stems may be at the same height,

b) Live stems may be below the height of the dead stems, and

c) Live stems may be taller than the dead stems.

The relationships would be produced as follows: The dead clusters of twigs form a zone of mechanical protection. The young stems that develop from the base of the shrub are typically not browsed until they extend beyond the dead stems. Once live stems extend above that mechanical protection, browsing begins and a new cluster of twigs develops. Under these circumstances, the base of current-year-growth is about the same height as the dead cluster of twigs (C and D).

As browsing pressure continues and the vigor of the shrub diminishes, the base of the current-year's-growth may fall below the level of the dead stems. Alternatively, if a plant is protected from browsing, the base of current-year's-growth will progressively grow above the height of the stems killed by browsing. These height relationships form the basis of one method of assessing trend during monitoring.

Stems from 20 plants were selected for measurement based on height and vigor. To meet the height criterion, the base of current-year-growth of the tallest stem had to be within the zone 75–200 cm above the ground. Stems in this region are exposed to browsing. Shorter plants were measured when necessary.

Table. 1. LD Index. This index applies to plants in which some stems have been killed by browsing. Values greater than zero indicate that the live stems have grown taller than the stems killed by browsing. Values near zero indicate that the stem is browsed at about the same level as the dead stems (dead stems provide mechanical protection from browsing). Values less than zero indicate that the plant is dying back to ground level.

Monitoring station	LD Index ± SE	Maximum value	Minimum value
	inches (cm)	inches (cm)	inches (cm)
1	–4.8 ± 2.1 (–12.3 ± 5.4)	11.4 (29)	-26.8 (-68)
2	–15.1 ± 3.9 (–38.3 ± 10.0)	0 (0)	(–61.0) (–15)
3	–3.3 ± 1.4 (–8.5 ± 3.5)	5.1 (13)	–19.3 (–49)
4	0.7 ± 2.2 (1.7 ± 5.5)	22.8 (58)	–12.2 (–31)

Of plants meeting the height criterion, the most vigorous were selected for measurement. The reasoning was as follows. For the full-statured community to persist, tall plants must be replaced as they die. The tall plants are relatively long-lived, so only a few young individuals must grow to full stature. For that reason, we biased sampling to include those plants that most likely would succeed. Plants were not marked for remeasurement in subsequent years; each year's sample is based on a new selection that might or might not include plants measured in previous years.

The height of the tallest stem was measured to the base of current-year-growth (H_{pyg}). Stems killed by browsing were identified by bite marks and clusters of twigs. Height was measured to the tip of the dead stem (H_D). The LD Index was calculated from: H_{pyg}–H_D. Values near zero indicate that browsing limits current-year-growth to the zone of mechanical protection. Negative values indicate that the community is in significant decline. Positive values indicate recovery.

The LD Index data indicate that Geyer willow is in decline at all monitoring sites; most current-year-growth that extends above the limit of mechanical protection is consumed during the winter (Table. 1).

At MS1, MS2, and MS3, the mean LD Index was less than zero, while the mean LD Index of 1.7 at MS4 was very close to zero. Out of the entire sample set of 80 stems, only 16 had LD Index values greater than 0, 9 of which were at MS4. The maximum LD Index value encountered was 58 cm; this stem was at MS4. The low LD Index values confirm what can be seen with the eye during the growing season. From a distance, many willow stands are brownish in color; stems with leaves are obscured by taller dead stems.

Trend assessment based on $NAGR_{L3}$. The second of the two monitoring methods is based on the minimum growth rate that will enable a stem to grow out of ungulate reach before it dies. Dead stems, such as those seen in Fig. 3, Part 1 (p. 29) above, are evidence that browsing can kill. It follows that heavily browsed stems have a limited period to grow out of reach. We determined the lifespan of heavily browsed stems by taking sections of dead stems (presumed to have been killed by browsing) and counting the number of annual rings. Most sections were taken from the region labeled DB in the figure above (Type D). The average age at death was 10.2 ± 0.3 years (± SE, N = 116, unpublished data).

We established a threshold $NAGR_{L3}$ value as follows. If a stem does not grow tall enough to escape browsing within about 10 years, dieback will occur. We used 2.5 m as the height of escape. To grow 2.5 m in 10 years, the stems must grow an average of 25 cm per year. Where other species are monitored at other locations, a corresponding stem lifespan and threshold growth rate would have to be determined.

The stems selected for LD Index measurement were also used for $NAGR_{L3}$ measurements. The following data were collected from each stem:

1. Lcyg (length of current-year-growth). In this example, assume that the data were collected in August 2000. The current-year-growth segment would have been produced the same growing season, that is, in 2000 (Fig. 5).
2. L1 (live length of the segment produced the previous year—i.e., in 1999.
3. L2 (live length of the segment produced the previous year—i.e., in 1998)
4. L3 (live length of the segment produced the previous year—i.e., in 1997)

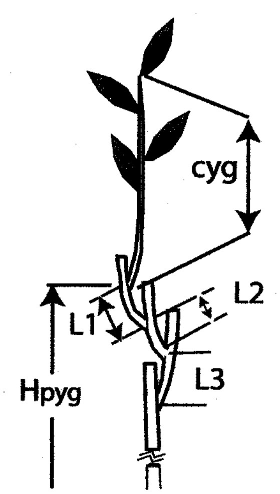

Fig. 5. ***Segments measured for LD Index.***

Table. 2. Net Annual Growth Rate (NAGR) based on the average stem length added during the previous three growing seasons. At Mt. Haggin, browsed stems have an average lifespan of about 10 years. To grow out of ungulate reach before they die, stems must have a Net Annual Growth Rate of about 10 inches (25 cm) per year or greater.

Monitoring station	$NAGR_{L3} \pm SE$	Maximum value	Minimum value
	inches (cm)	inches (cm)	inches (cm)
1	4.4 ± 1.0 (11.2 ± 2.5)	20.4 (51.7)	0.5 (1.3)
2	3.3 ± 0.6 (8.5 ± 1.5)	11.3 (28.7)	0.7 (1.7)
3	3.9 ± 0.6 (9.9 ± 1.5)	9.4 (24.0)	1.1 (2.7)
4	5.6 ± 0.9 (14.2 ± 2.4)	13.5 (34.3)	0.8 (2.0)

The growing season years were determined by inspection of terminal bud scars. If a complete annual increment died, the length for that year would be entered as zero. For example, if the segment produced in 1998 died, the 1999 segment might develop from the 1997 segment. The remains of the 1998 segment would be identifiable from terminal bud scar relationships. Because the 1998 segment did not contribute to live stem length, its value—with respect to growth rate—is zero.

Because monitoring data will be collected each year, we need to be able to distinguish between data collected in different years. A two-part nomenclature is used. The first part refers to the segment type (Lcyg, L1, L2, or L3); the second part, written as a subscript, refers to the year in which the data were collected. For example, $L1_{2000}$ refers to an L1 segment that was measured in 2000.

Growth that occurred during a single year can be tracked over a subsequent three-year period. For example, $L1_{2001}$, $L2_{2002}$ and $L3_{2003}$ would all be expressions of the fate of current year growth produced in 2000.

The net annual growth rate for the preceding three years ($NAGR_{L3}$) was calculated by (L1 + L2 + L3)/3. The resulting value was compared to the threshold value of 25 cm / year.

Mean $NAGR_{L3}$ values for all four sites were well below the threshold value of 25 cm/year (Table. 2). Of the 80 stems sampled, only 7 exceeded the threshold value; 5 of these were at MS4.

The $NAGR_{L3}$ method of measuring growth rate is rapid and nondestructive. However, there are sources of error that should be considered. Under heavy browsing pressure, stems undergo cycles of growth and dieback. During periods of dieback, some stem segments will likely be within the protective zone of dead stems. Such stems will have larger $NAGR_{L3}$ values compared to stems where all segments were exposed to browsing. Factors unrelated to browsing may reduce growth rate. For example, current year growth values in drought years might be lower compared to values in moist years.

Browsing may inhibit height growth in three ways. First—and most obvious—consumption removes material that would otherwise have contributed to height. Second, browsing-induced stress may reduce growth potential. Third, browsing may inhibit height growth by running out the stem's biological clock. Young stems elongate rapidly when they are young, and slow down as they mature. Because intensely browsed stems undergo cycles of dieback, a 1-m-tall stem might be 10–20 years old at the base. On such stems, we have observed that current-year-growth is sometimes only a few cm in length. Such stems might have entered into an age-related phase of reduced growth.

Summary Of Trend

The surveys and monitoring conducted at Mt. Haggin Wildlife Management Area in 2000 indicate that Geyer willow is in decline. During the field surveys, no individuals exposed to browsing were found to have uninterrupted-growth- or released-type architectures. During monitoring, we sampled the most vigorous plants. The LD Index data indicate that current-year-growth is browsed back to the level of mechanical protection. The preponderance of negative LD Index values indicates that major dieback has already occurred. The site-wide average $NAGR_{L3}$ values are well below the threshold value of 25 cm/year.

The quantity of available browse will diminish as dieback progresses. If the moose population remains approximately constant, increased pressure will be placed on the remaining browse plants. All lines of evidence indicate that, if present trends continue, the willow community will likely be converted to a meadow. To reduce browsing pressure, the moose harvest quota was increased by 50% for the 2000 hunting season. During the winter of 2000/2001, snow depth was markedly less compared to typical years. The reduced snow pack allowed moose to disperse over a broader area compared to years in which snow is uniformly deeper. These factors are expected to influence willow growth. To document that response, we will conduct surveys and monitoring on an annual basis.

About the authors: *Richard B. Keigley, Ecologist, U. S. Geological Survey, Biological Resources Division, 632 Coulee Drive, Bozeman, MT 59718. Michael R. Frisina, Range Coordinator, Montana Fish, Wildlife, & Parks, Butte, MT, 59701-2112. Craig W. Fager, Wildlife Biologist, Montana Fish, Wildlife & Parks, 1820 Meadowlark Lane, Butte, MT, 59701*

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